A Monitoring and Warning System for Close Geosynchronous Satellite Encounters

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SPACE CONTROL CONFERENCE

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Outline

- Geosynchronous satellite failures
- Geosynchronous Monitoring and Warning System
- Preliminary results
- Summary and future work

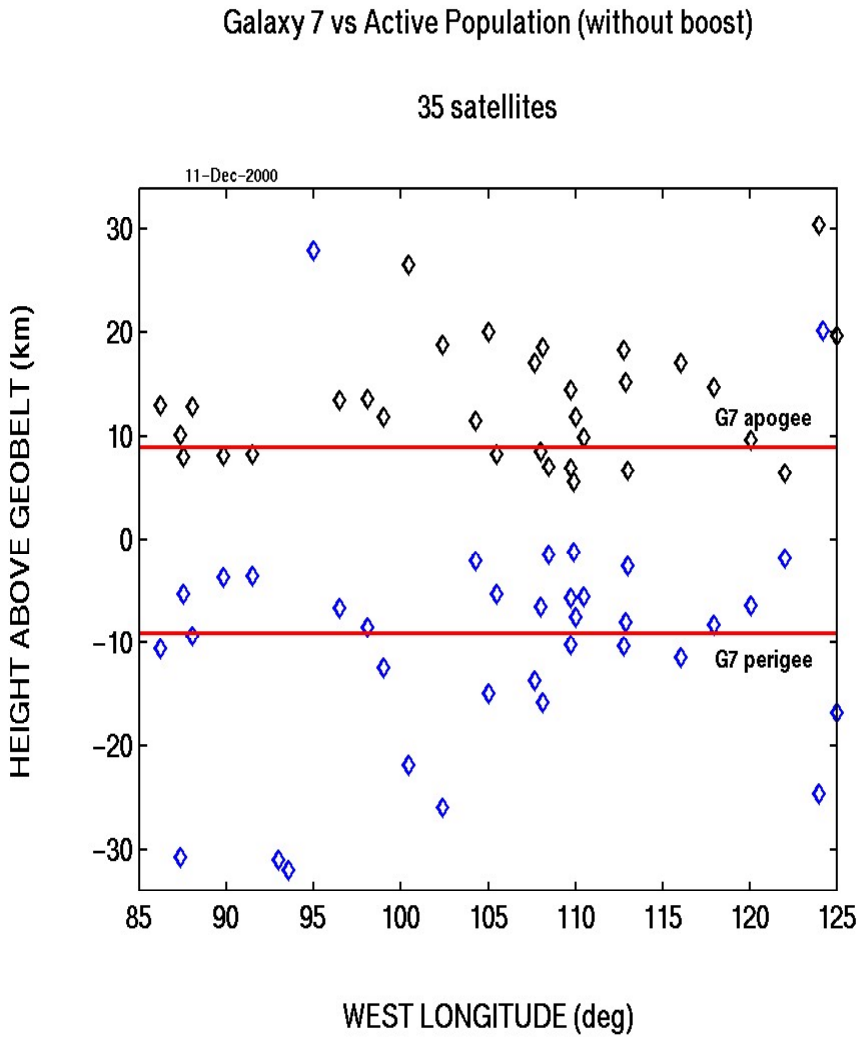
Drifting Satellites in the Geopotential Well Centered at 105.3 W Longitude

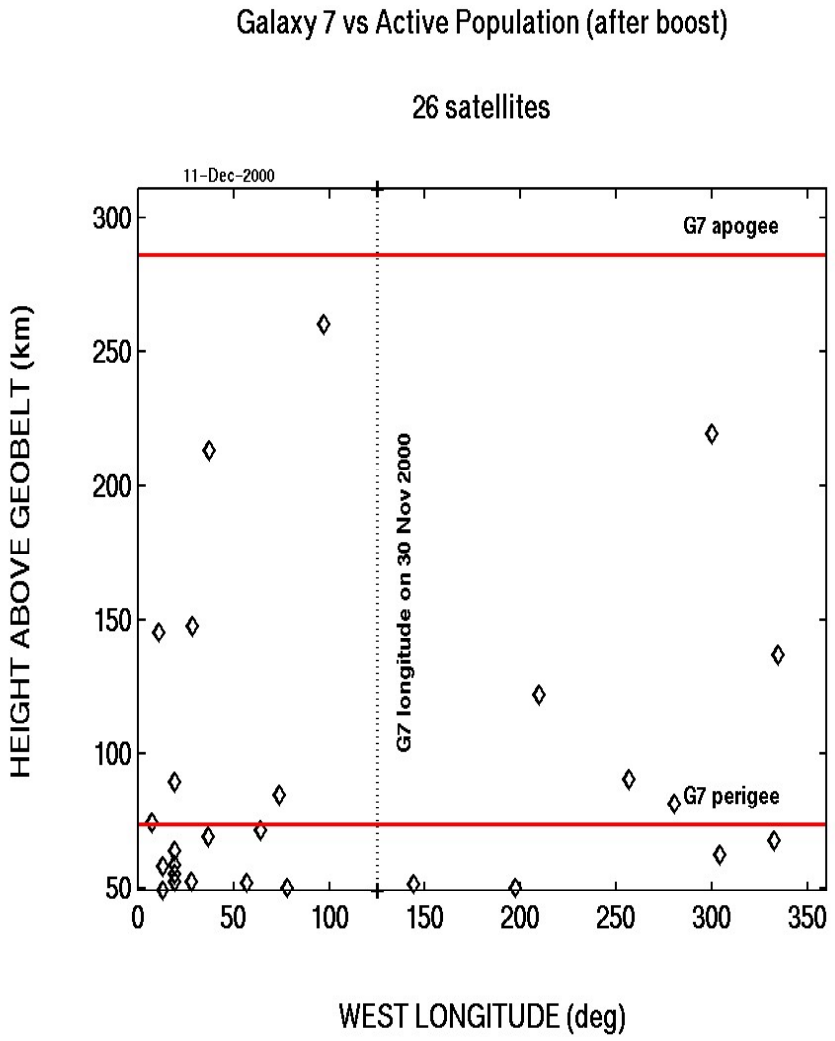
- Telstar 401 failed January 11, 1997
  - Oscillates indefinitely from 97° to 115° W longitude with period ~ 800 days
  - Since failure, has encountered over 100 satellites with closest distances ~ 2 km
  - 27 close approaches predicted for 2001
- Solidaridad 1 failed August 29, 2000
  - Oscillates indefinitely from 101° to 109° W longitude
  - Encounters in Geopotential Well began in late January
  - 11 close approaches predicted for 2001

Galaxy 7

- Galaxy 7 failed November 24, 2000
- Galaxy 7 normally oscillates in Geopotential Well from 125 to 85° W longitude
  - It would have encountered a considerable number of satellites
- Galaxy 7 not completely dead, thrusting capability exists
- Operator performed boosting maneuvers in late November
  - Current perigee above GEO = 74 km
  - Current apogee above GEO = 286 km
  - Circulates moving West at about 2°/day
  - 26 satellites in the GEO belt are in the above Perigee to Apogee range, monitoring will look for any potential encounter

Galaxy 7 Encounter Population Before and After Boost

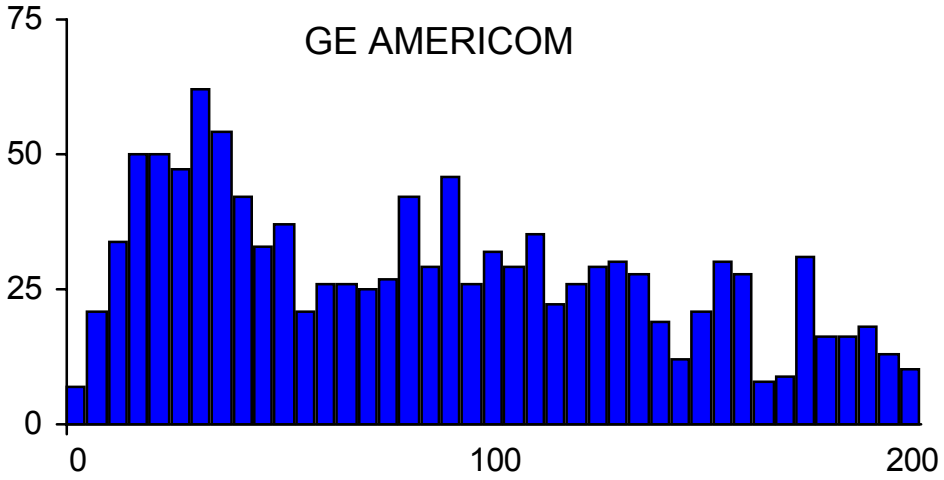


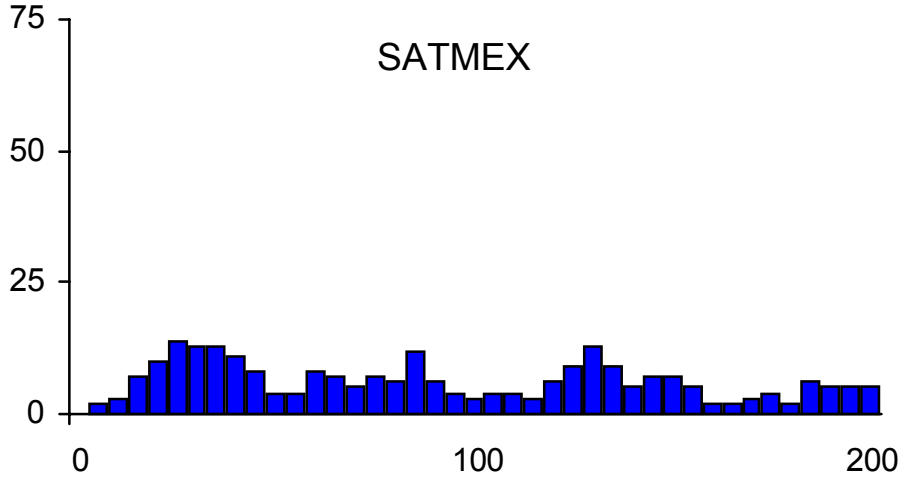


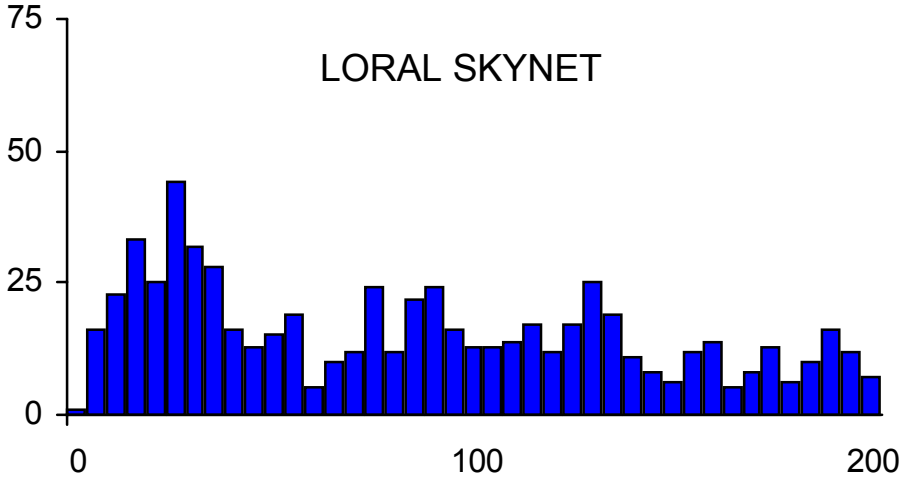
GEA CRDA Background

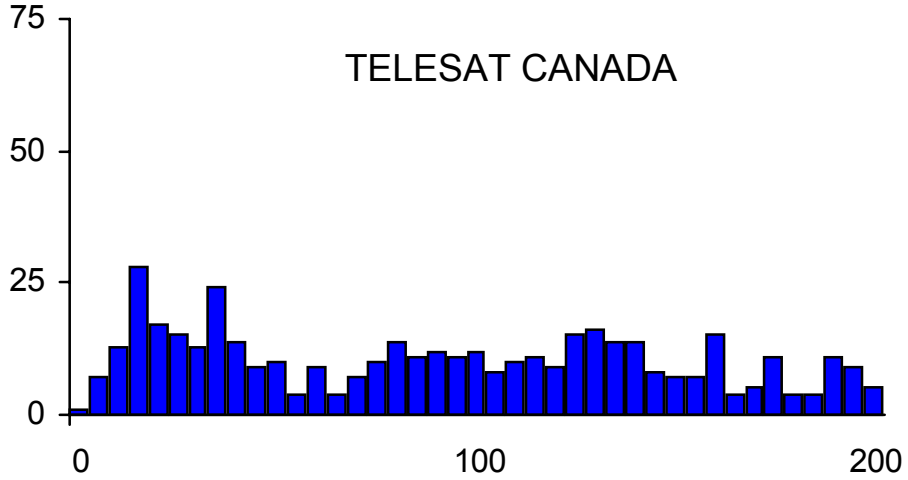
- MIT Lincoln Laboratory became involved in monitoring first encounters of Telstar 401 with Geopotential Well satellites
- Resources
  - Millstone Hill Radar with accuracy : 5 m range, 3mm/s range rate, 5 – 10 mdeg azimuth and elevation
  - Space Based Visible telescope with 1 mdeg RA and DEC
  - High precision orbit determination DYNAMO (Force models to 1 m)
- MIT Lincoln Laboratory established Geosynchronous Encounter Analysis Cooperative Research and Development Agreement (GEA CRDA) with commercial satellite owners/operators
  - CRDA initially monitored the threat posed by Telstar 401, expanded to monitor threats to all CRDA partner satellites
  - GE Americom (18 Satellites), Loral Skynet (7 Satellites), SATMEX (3 Satellites), TELESAT Canada (6 Satellites)
- Operational aspect of CRDA
  - Monitor encounters of CRDA satellites with threatening RSOs
  - Calibrate CRDA partner range data either by processing the range data or providing high accuracy element sets to partners

Estimated Encounters vs. Distance of Closest Approach for 2001









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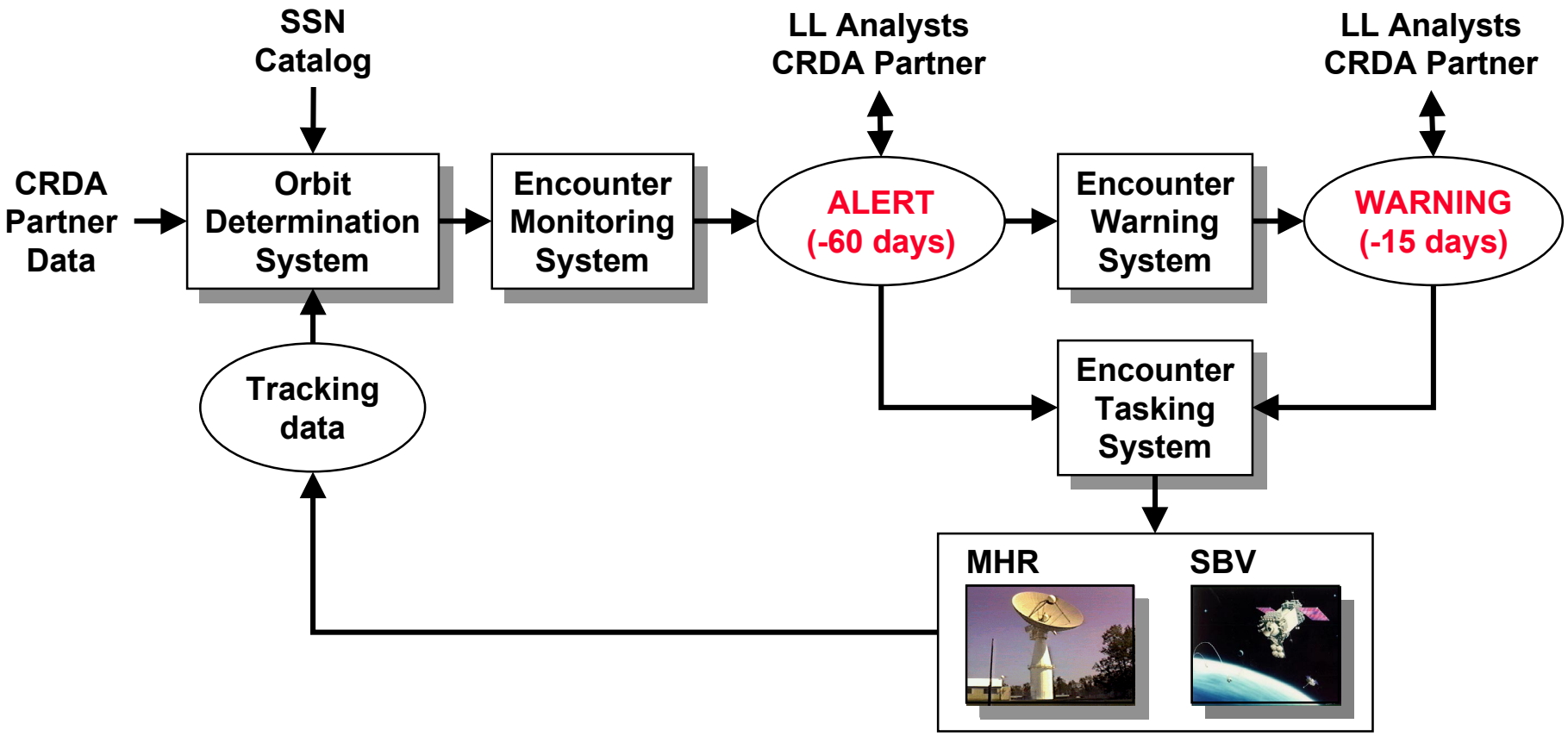
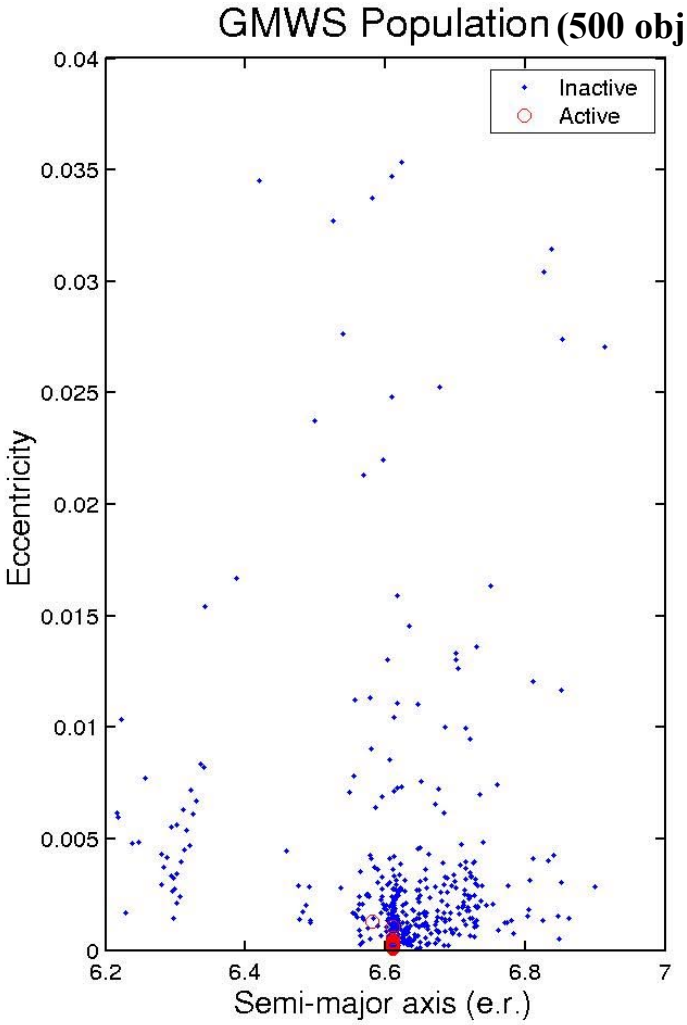
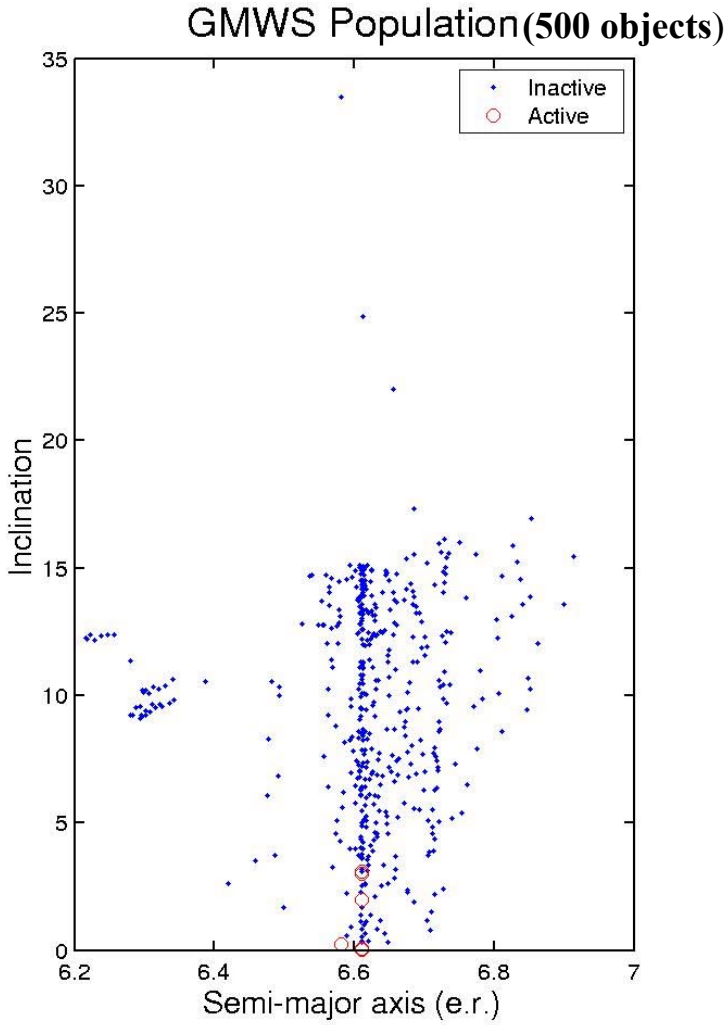
Geosynchronous Monitoring and Warning System (GMWS)



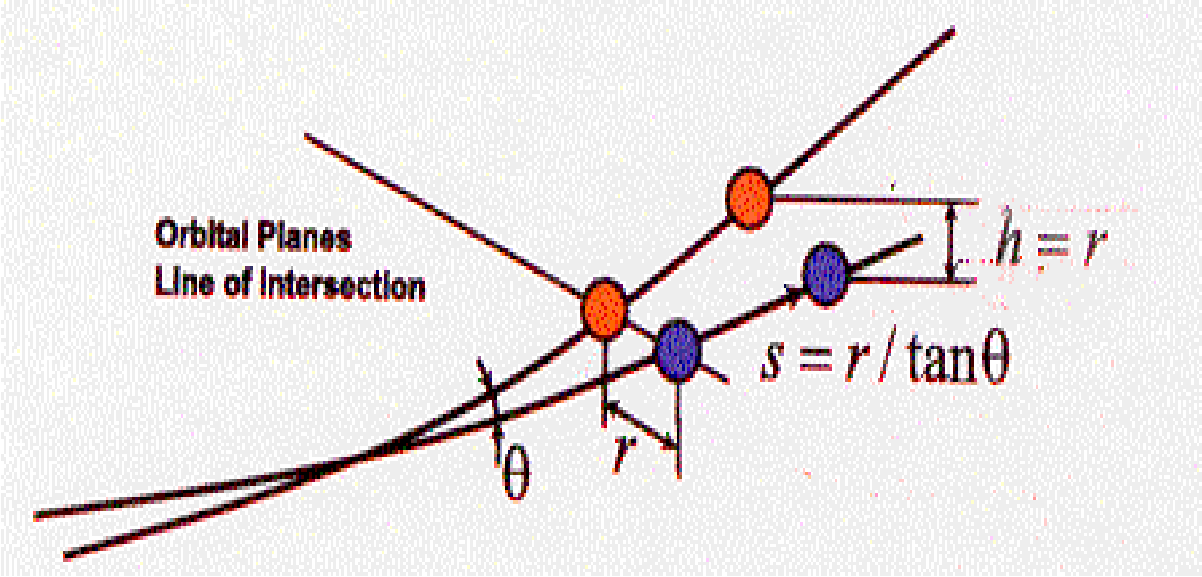
GMWS Population





Encounter Determination for ALERTS (1)

- ALERTS determines encounters based on orbital plane intersection of two objects
  - $|a_1 - a_2| \leq a_1 e_1 + a_2 e_2$ requires Perigee of one object to be greater than the Apogee of the other (necessary but not sufficient condition)
  - Orbit planes are generally inclined, an object threatening the GEO belt must cross the equator near GEO radius
  - Due to typical sizes of GEO satellites an encounter is localized to point at which orbital planes intersect



Encounter Determination for ALERTS (2)

- Objects also need to be at point of intersection at same time
- At time one object is at point of intersection, compute longitudes and radial distances of both and check:

$$\left|L_2 - L_1\right| \le L_{\ threshhold} \qquad \left|r_2 - r_1\right| \le r_{\ threshold}$$

$$where\ L_{\ threshold} = 0.05\,\text{degrees}$$

$$R_{\ threshold} = 50km$$

Encounter Determination for WARNINGS

WARNINGS determine encounters based on 15 day DYNAMO ephemeris

- **DYNAMO orbit propagated 15 days in ECI coordinates at 60 s spacing**
- **ECI vectors differenced, transformed to Radial, Along Track, and Cross Track Differences to show encounter distances in physically meaningful components**
- **Encounters tabulated and prioritized for tasking**

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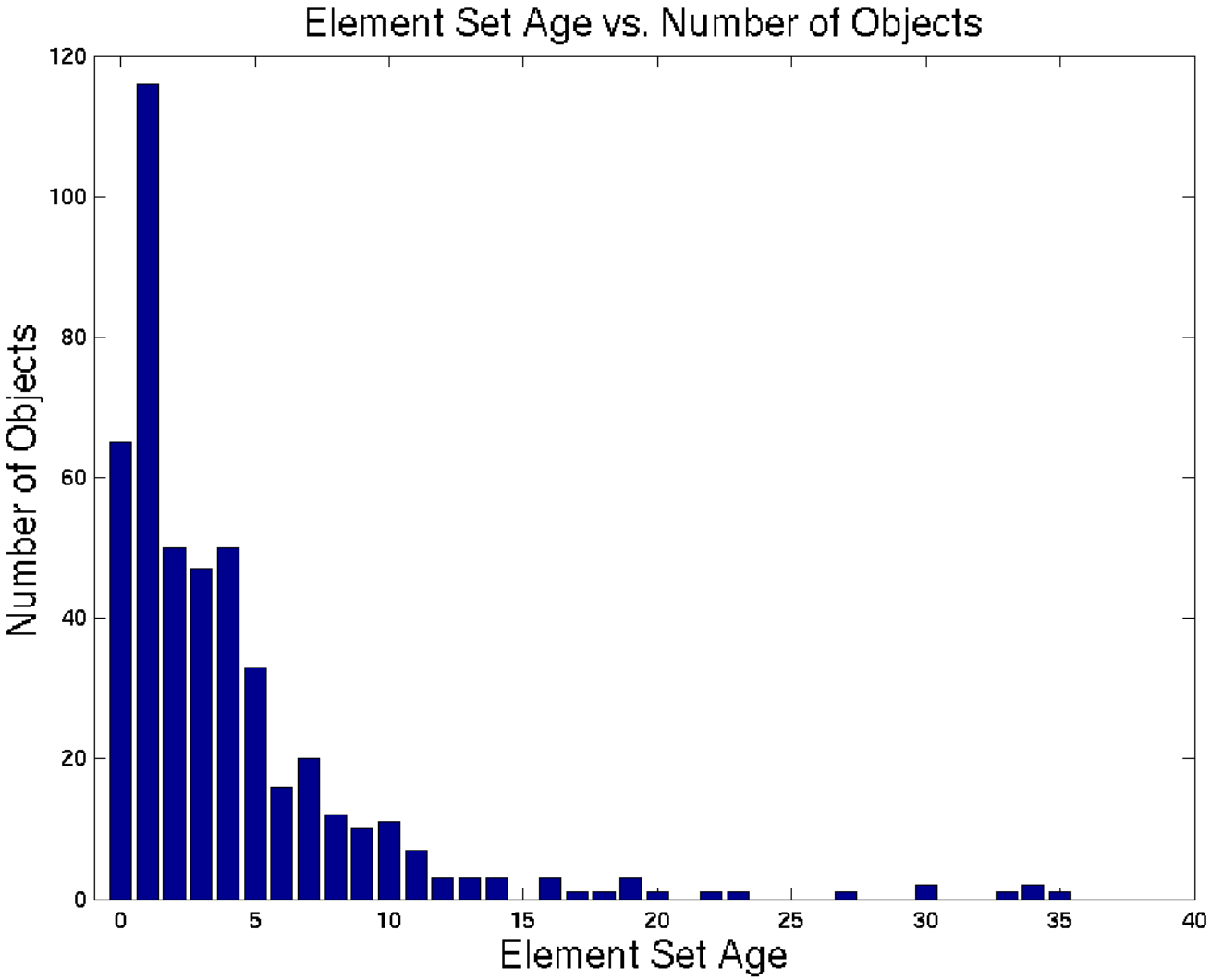
GMWS Validation

- GMWS system runs daily
  - Updates orbits based on new tracking
  - Generate ALERTS and WARNINGS
  - Generates necessary tasking to improve encounter estimation
- A number of system checks are made to ensure that all components are running properly
- Validating the results:
  - Examine age of element sets
  - Examine orbit and encounter prediction accuracy
    - Orbits overlapped over semi independent (10% overlap) fit spans
    - Predicted orbit accuracy assessed by predicting backwards
  - Track with radar during closest approach to confirm predicted encounter distance and time

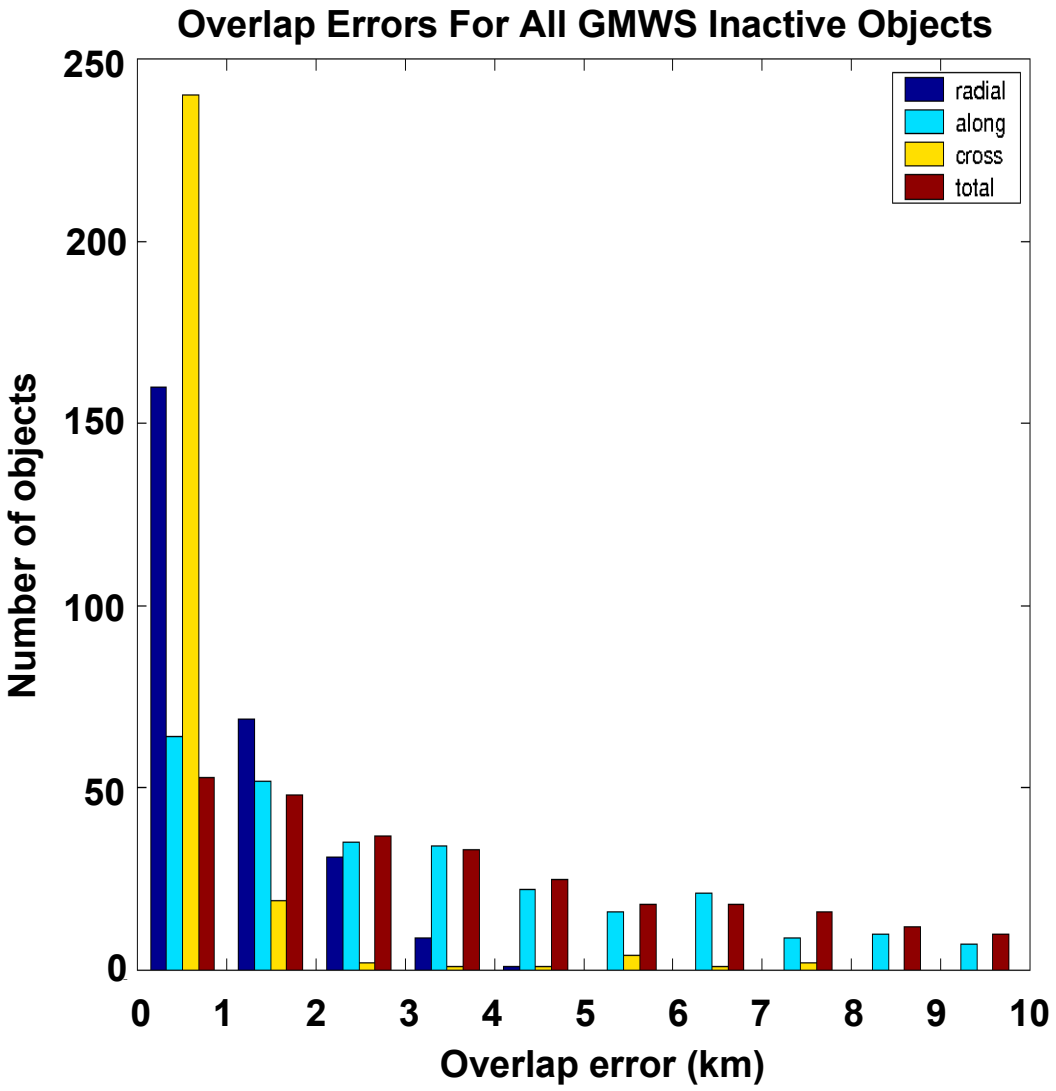
Element Set Ages for the GMWS Catalogue



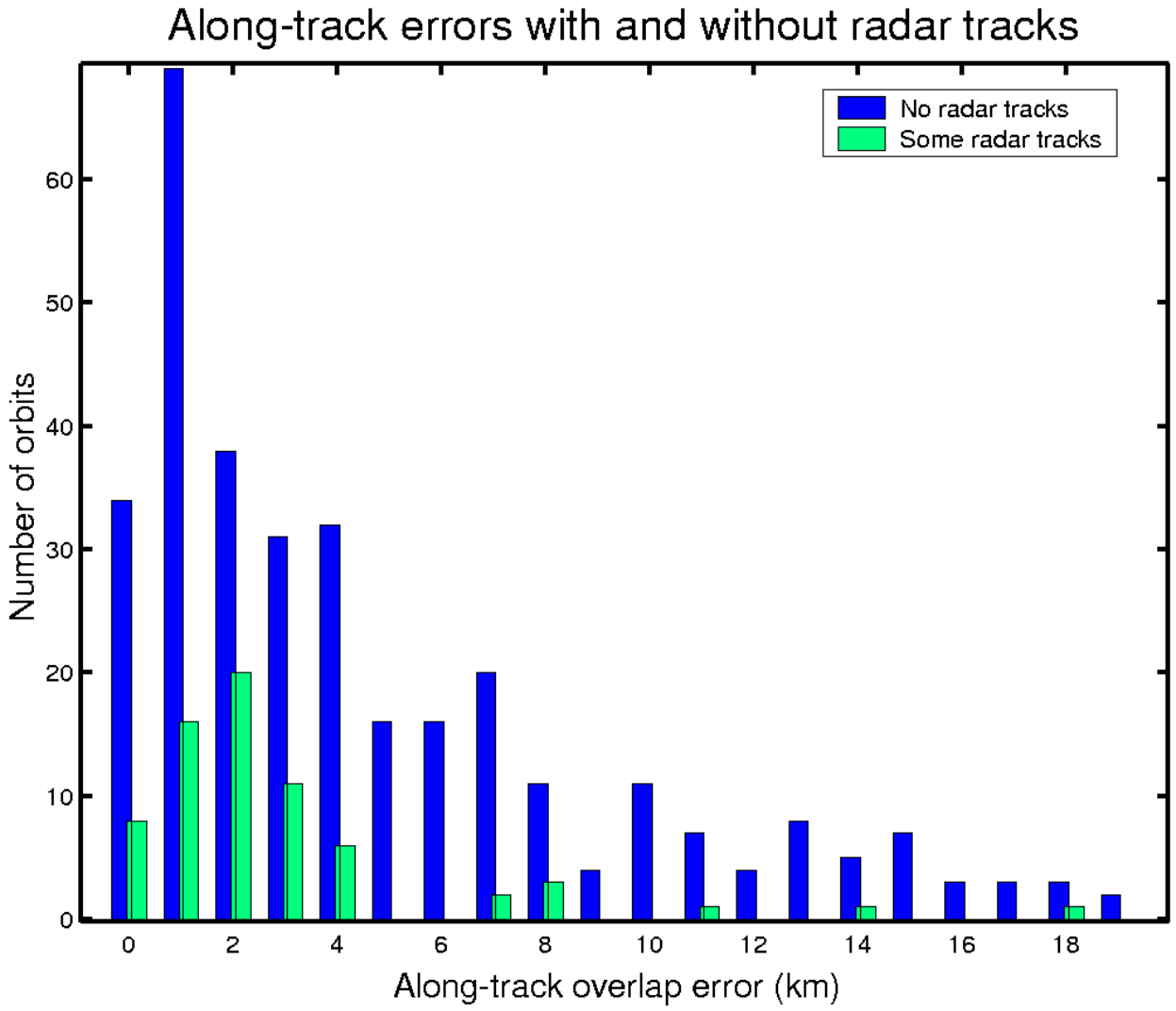
GMWS: Orbit Accuracies by Overlap

- **GMWS Deep Space Catalog**
  - 477 orbits computed
    - 443 inactive
    - 34 active
  - 472 DYNAMO orbits
  - 408 objects have orbits determined from optical observations only

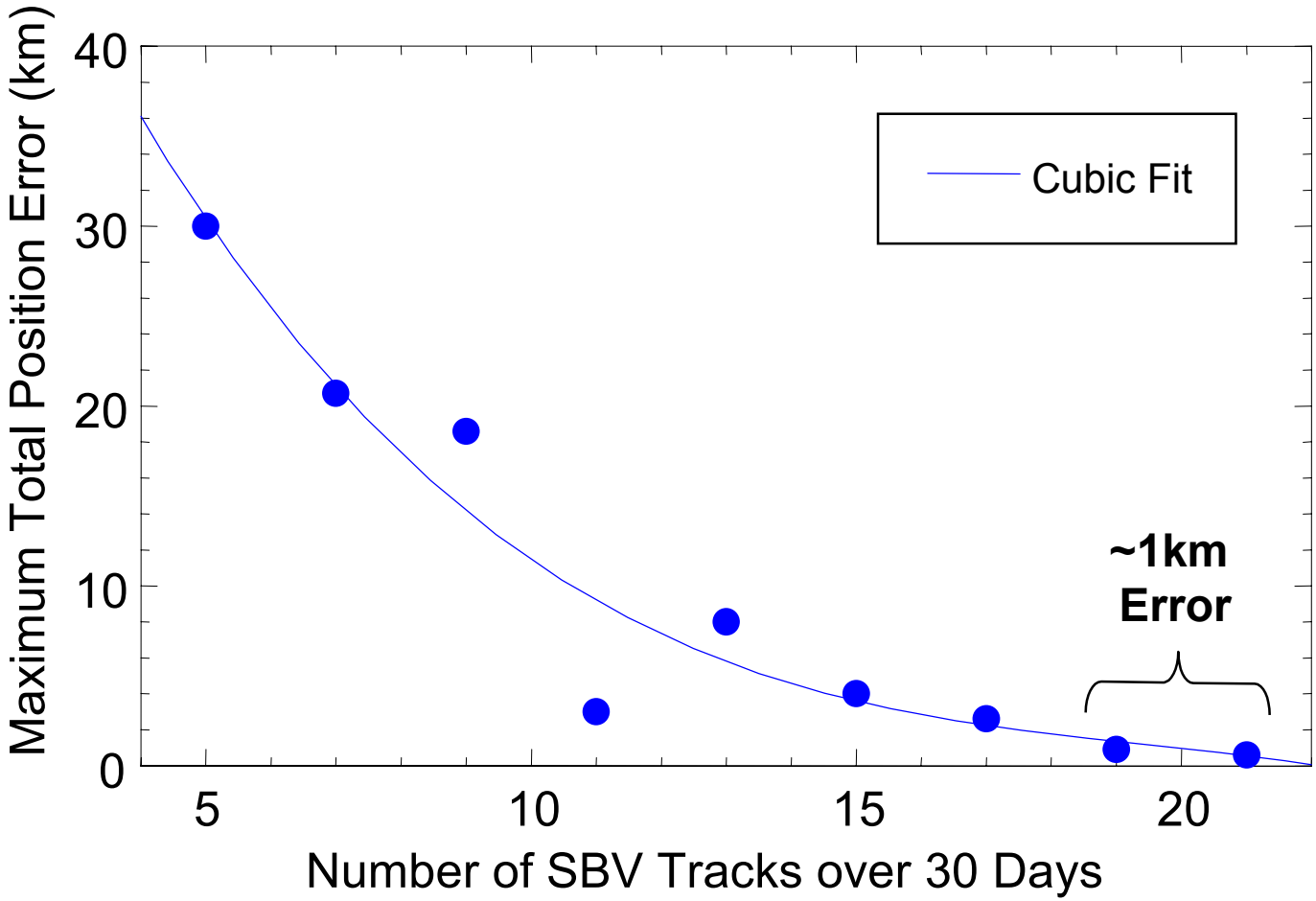
- **GMWS Inactive Objects**
  - 443 inactive objects
  - 346 (78%) have overlap errors measured
    - 331 (96%) have errors < 50 km
    - 256 (74%) have errors < 10 km
    - 189 (55%) have errors < 5 km
    - 52 (15%) have errors < 1 km



GMWS Along-Track Error Distribution

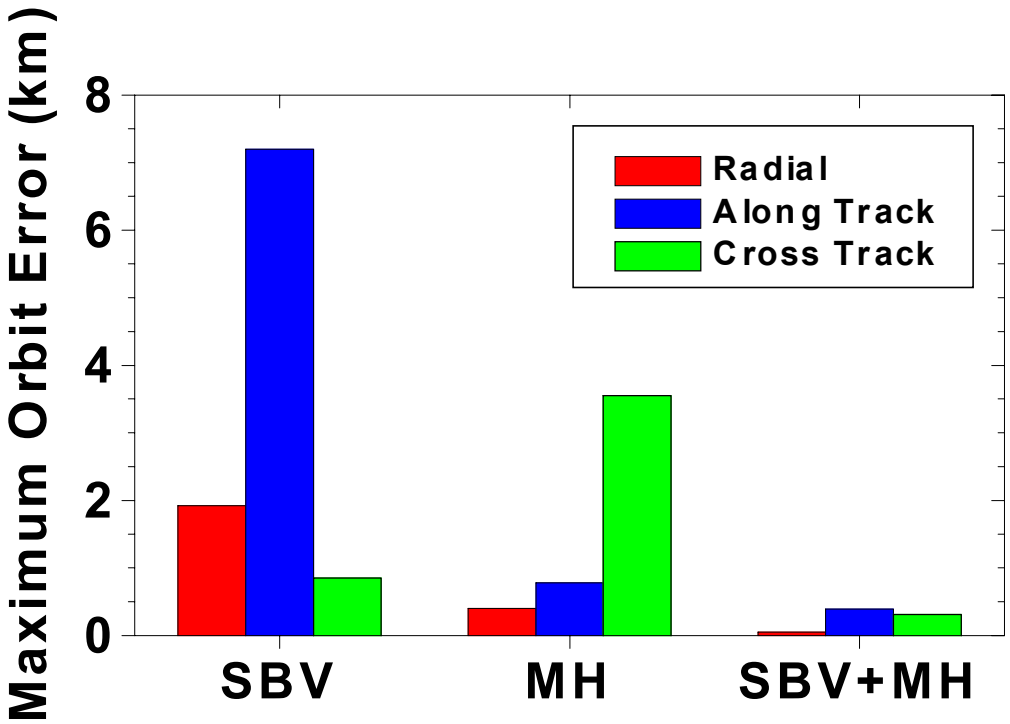


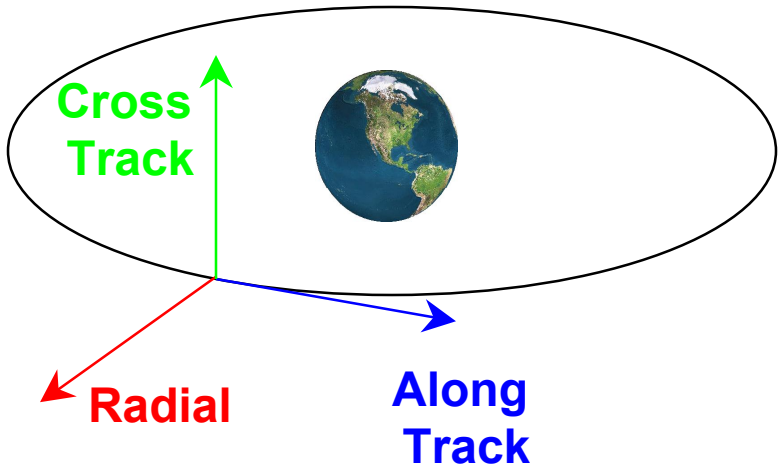
SBV Only High Accuracy GEO Orbits



SBV capable of generating high accuracy GEO orbits

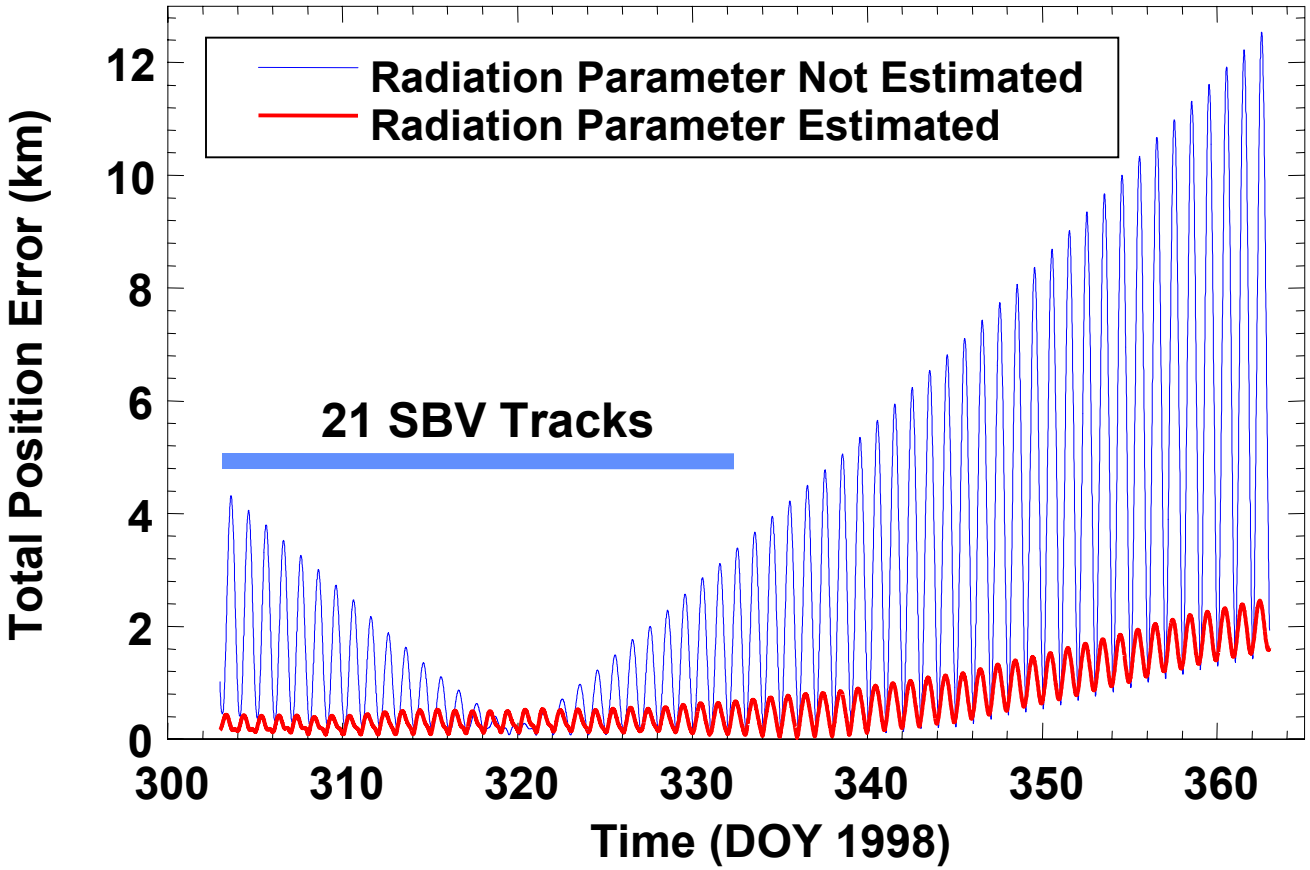
SBV and Radar Data Fusion





- Two week observation span
  - 6 SBV tracks
  - 3 Millstone (MH) tracks
- Optical and radar data are complementary
- Optimize data collection to achieve a given accuracy

Effect of Accurate Radiation Pressure Modeling



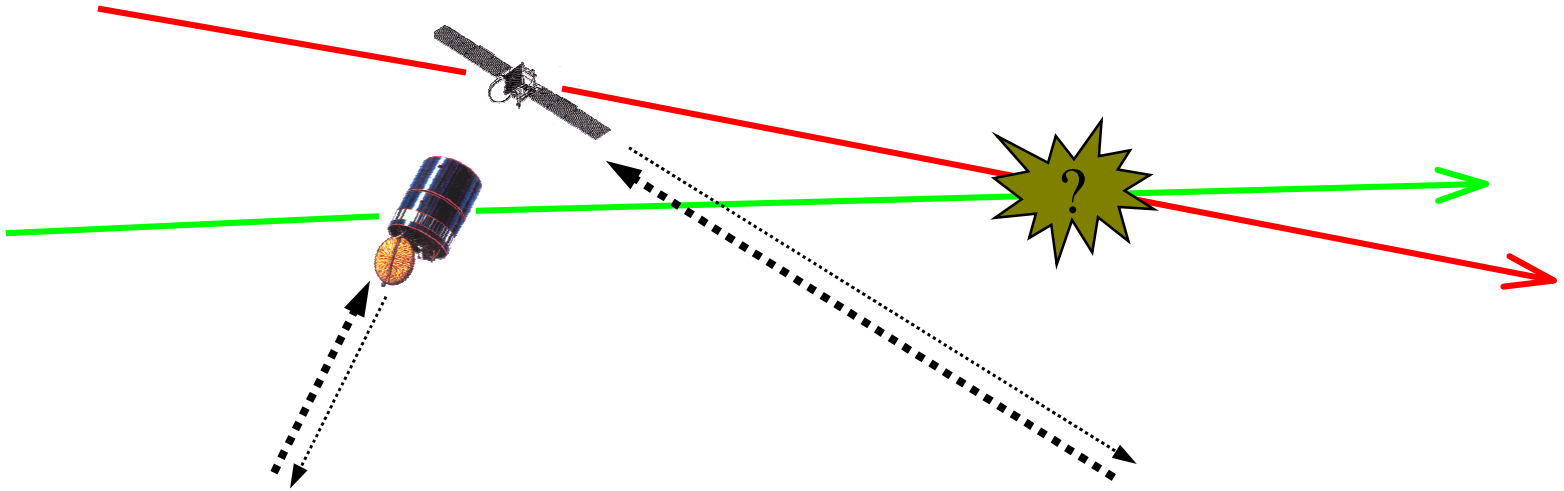
- Radiation parameter error significant source of prediction error

Orbit Accuracy Improvement by Adding CRDA Partner Range Data

Tracking Case	ΔRad RMS(m)	ΔCross RMS(m)	ΔAlong RMS(m)	ΔRSS (m)
Millstone Only	132	1236	268	1272
Millstone + Telesat	9	61	17	64

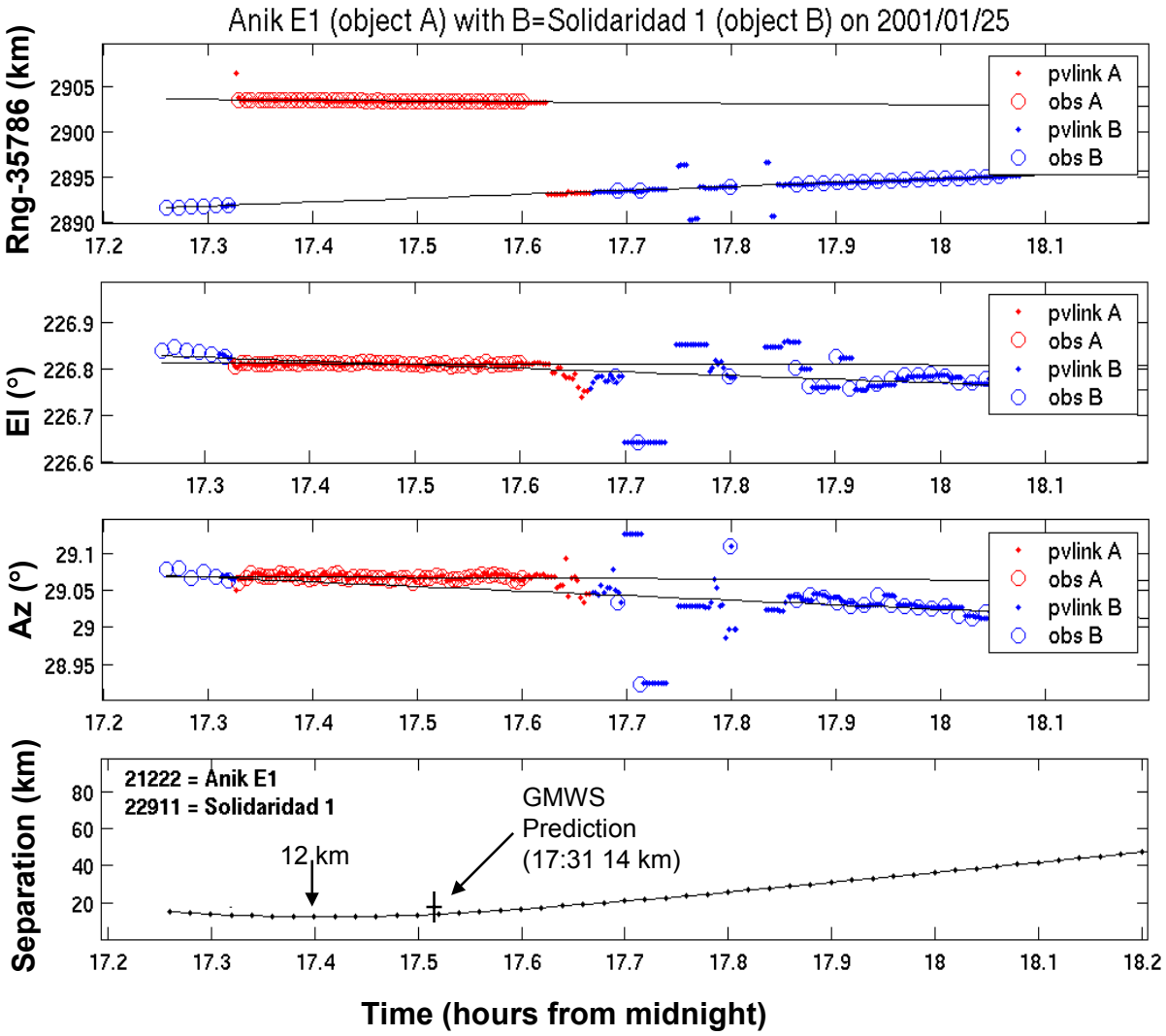
- Orbit Accuracy Assessment of Anik E1 (Telesat Canada) by Overlap

Encounter Validation
With Millstone and Haystack Radars



- Millstone and Haystack each track one of the encountering objects
- Observations are later combined, giving a three-dimensional picture of the encounter (in azimuth, elevation, and range)
- If Haystack is unavailable, Millstone alternates between objects

Single-Radar Encounter Validation



Summary and Future Work

- GMWS is currently monitoring a catalogue of ~ 450 inactive and 34 CRDA partner satellites
  - GMWS generates close encounter ALERTS 60 days out followed by WARNINGS 15 days out
  - MHR and SBV tasking requested as needed to enhance accuracy of encounter prediction
- Accuracy measures from GMWS currently show 75% with errors < 10 km and 50% with errors < 5 km
  - Enhanced using radar, radiation pressure scale factor, longer arcs if optical only
- Calibrated CRDA partner range and timely maneuver information important to enhance tracking resources
- Accuracy assessment, maneuver detection, active vs. active, and precision longitude monitoring are current priority Research and Development components for GMWS